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No. 448

EFFECT OF AILERON DISPLACEMENT ON WING CHARACTERISTICS

By R. H. Heald
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SUMMARY

The effect of aileron displacement on wing character-
istics has been investigated for the Clark Y and U.S.A. 27
wing sections equipped with rectangular ailerons. The
airfoils, rectangular in plan, and having a 10-inch chord
and 60-inch span, were mounted on a model fuselage. Two
sets of ailerons, both of 20-inch span, were used, the
chord for one set being 2 inches, for the other 3 inches.
Measurements were made for angles of pitch of 0°, 12°, 20°,
and 40°.

When both ailerons were displaced equally in oppo-
site directions (the conventional arrangement), the lift
was reduced, the drag increased, and the center of pres-
sure moved forward. When one aileron was displaced down-
ward, the lift was increased, the drag was increased, the
center of pressure remained in nearly the same position.
When one aileron was displaced upward, the lift was de-
creased by an amount greater than that observed for the
conventional arrangement, the drag was decreased for a
large part, although not all, of the range of aileron dis-
placement investigated, and the center of pressure moved
forward by an amount not greatly different from that ob-
served for the conventional arrangement.

The one-aileron and two-aileron methods of determin-
ing the characteristics of the conventional arrangement
were compared and the agreement found to be satisfactory.

The investigations were conducted in the Bureau of
Standards 10-foot wind tunnel in cooperation with the Aero-
nautics Branch of the Department of Commerce and with the
National Advisory Committee for Aeronautics.

INTRODUCTION

The changes in wing characteristics which take place
as a result of aileron movement are of importance in con-
nection with the suggested use of one aileron, displaced
upward, as a possible means of securing improved lateral
control. The effects of the downward displacement of a
flap on the lift, drag, and pitching moment of an airfoil
have been investigated experimentally by Nayler and oth-
ers. (References 1 and 2.) The effects of aileron dis-
placement, especially those arising as a result of the
upward displacement of a single aileron, or the simulta-
neous displacement of both ailerons in opposite directions
have not been experimentally defined. A theoretical treat-
ment of the subject is given by Wieselsberger in reference
3.

Measurements to determine the effect of aileron dis-
placement are often made using a single aileron. The re-
sults for the conventional arrangement, in which ailerons
on opposite wings are displaced through equal angles but
in opposite directions, are then obtained by computation.
This procedure neglects the possible existence of mutual
interference when both ailerons are displaced simultaneous-
ly. Although an investigation of this effect has been
made previously (reference 4), it seemed desirable to con-
duct the experiments so that a somewhat more detailed com-
parison could be made of the results obtained by means of
the one-aileron and two-aileron methods.

METHODS OF MEASUREMENT

In order to make the results of this investigation
comparable with those given in references 3, 4, and 5,
the same fuselage and airfoils were used. The principal
dimensions are given in chord lengths in Figure 1a. It
will be noted from the figure that the wing is set at an
angle of $+4^\circ$ to the axis of the fuselage and therefore
the angle of attack of the wing is always 4° greater than
the angle of pitch to which the measurements in this re-
port are referred.

For the determination of lift, drag, and pitching mo-
ment the model was suspended in an inverted position at
the center of the air stream by means of four small steel
wires attached to an adjustable frame above the tunnel.

(Fig. 1b.) The weight of the frame, model, and counter-
weight W_1 was supported in part by two balances of the
pendulum. type B and B_1 and, in part, by a counter-
weight W acting, by means of a lever, on the horizontal
member H of the frame. The connection of this member
of the frame to the pitching moment balance B was a
point-pulley bearing C. The member H was maintained
horizontal during a run by adjusting the screw N accord-
ing to the indications of a sensitive level mounted on H.
Adjustments of the model in pitch were accomplished by
tilting the movable member of the frame A, about the
axis O_2. The pitch angles were set off on a scale marked
on the sector S, and were checked before and after a run
by direct measurement of the distances from the extremi-
ties of the fuselage axis to a horizontal reference plane
established for the purpose.

In order to stabilize the model with the wing span
horizontal, i.e., the condition of zero roll, the mova-
ble counterweight W_1 was attached well below it. Small
stay wires connected this weight with the wing tips. Dur-
ing a run the counterweight was moved laterally in its
fairing a distance sufficient to give a countermoment ap-
proximately equal in magnitude to the rolling moment im-
posed by the aileron displacement. The yawing moments
were balanced by the torsional restoring moment of the
wire suspension system. The resulting angle of roll was
less than 2^O, the angle of yaw less than 1^O.

When measurements are made using this apparatus the
lift of the model is equal to the sum of the net readings
indicated by the balances B and B_1. The drag is deter-
mined from the observed deflection due to the wind, the
weight W_1 being free to follow this deflection. The to-
tal drag is equal to the combined weights of the model,
wires, and lower counterweight plus the lift, times the
tangent of the angle of deflection. The net drag is equal
to the total drag minus the wire drag, which is computed
from the diameter and length of the wire and the air speed.
The pitching moment about the point of attachment O, of
the front wires to the model, referring again to Figure
1b, is determined as follows: The total pitching moment
caused by the wind on the model about point O will be
equal in magnitude to the total moment about the point
O_2. The experimental apparatus, however, is designed to
measure the magnitude of the moment about O_1 instead of
O_2. A correction to the observed moment is accordingly
necessary. Since O_1 is located vertically below O_2,

that is, in a direction from O_2 parallel to the lift force, and the entire drag force on the model is opposed by a reaction at O_1, the effect of the correction will be to diminish the observed moment by the value of the total drag times the distance between O_1 and O_2. The total drag is the sum of the drag of the model and the drag of suspension wires exposed to the air stream. The corrected moment about O_1 is therefore equal to the pitching moment acting about the cross-wind axis through point O on the model. Lift, drag, and pitching moment observations are made simultaneously. Rolling and yawing moments have been determined previously. (References 3 and 4.)

The 20 by 2 inch and the 20 by 3 inch ailerons mounted on the Clark Y wing and ailerons of the same sizes mounted on the U.S.A. 27 wing were used in this investigation. The observations were made at a wind speed of 40 feet per second corresponding to a Reynolds Number of 210,000.

NOTATION

S = wing area (sq.ft.)

c = wing chord (ft.)

V = air speed (ft./sec.)

$q = \dfrac{\rho V^2}{2} = 0.001189V^2$

L = lift (lb.)

D = drag (lb.)

$C_L = \dfrac{L}{q S}$

$C_D = \dfrac{D}{q S}$

M_0 = pitching moment about the point of attachment of front wires, $-O$.

$$C_M = \frac{M_o\,^*}{q\ c\ S}$$

C_p $\}$ ratio* to the chord of the distance of the center of pressure from the projection of the leading edge on line A-A, Figures 5-9.

COMPARISON OF THE ONE-AILERON AND TWO-AILERON METHODS

In studying the effects of aileron displacement it is often convenient to use a model of half span and a reflecting plane or to use the complete wing with a single aileron. When either of these methods is used, as, for example, in determining rolling and yawing moments, the total moments are obtained by adding, algebraically, the net values for corresponding upward and downward displacements, determined from runs on one aileron. It is assumed that the values so obtained are equal to the values which would be obtained from the simultaneous displacement of both ailerons in opposite directions. Because this method does not take account of mutual interference between the ailerons, its validity has been questioned.

The effect of mutual interference has been investigated previously in the Bureau of Standards 10-foot wind tunnel in connection with the study of rolling and yawing moments and has been found to be of the same order of magnitude as the experimental error, and accordingly negligible in practical performance estimates. As a further check, tests were made on the model (figs. 1,a and 1,b) in

*It is customary and desirable when the model represents a specific airplane to refer the coefficients of pitching moment to a moment center corresponding to the center of gravity of the full-scale airplane and to refer the center of pressure coefficients to the thrust line, which may or may not coincide with the axis of the fuselage. Since the model used in these tests does not represent a specific airplane but rather a general type, it seemed unnecessary to carry through this refinement. The pitching moments with respect to any moment center other than that used, or the center of pressure positions with respect to any fixed point on the fuselage, are readily determinable from the data given either graphically or by computation. The pitching moment coefficients have been included in the tables in order to illustrate the degree of agreement between the one-aileron and two-aileron methods.

connection with the study of the lift, drag, and pitching
moment characteristics. The work of the 20 by 2 inch and
the 20 by 3 inch ailerons mounted on the Clark Y and U.S.A.
27 wings for 0° pitch was extended to form this part of
the investigation. The procedure used in determining the
combined values is best described by means of symbols.
Let L_0, D_0, and M_0 represent, respectively, the abso-
lute lift, drag, and pitching moment coefficients* for
the model with the ailerons neutral. Let ΔL, ΔD, and
ΔM represent the changes in lift, drag, and pitching mo-
ment coefficients when the ailerons are displaced. Also
let the subscripts r and l represent the right and
left ailerons, respectively, and the subscripts u and
d represent the direction of the displacements, upward
and downward, respectively.

The changes in the coefficients for the model when
the ailerons are displaced are represented by

ΔL_{ru}, ΔD_{ru} and ΔM_{ru} — when the right aileron is displaced upward,

ΔL_{lu}, ΔD_{lu} and ΔM_{lu} — when the left aileron is displaced upward,

ΔL_{rd}, ΔD_{rd} and ΔM_{rd} — when the right aileron is displaced downward,

and

ΔL_{ld}, ΔD_{ld} and ΔM_{ld} — when the left aileron is displaced downward.

The mean changes in L, D, and M are:

$$\Delta L_u = \frac{(L_0-L_{ru}) + (L_0-L_{lu})}{2}; \quad \Delta L_d = \frac{(L_0-L_{rd}) + (L_0-L_{ld})}{2}$$

$$\Delta D_u = \frac{(D_0-D_{ru}) + (D_0-D_{lu})}{2}; \quad \Delta D_d = \frac{(D_0-D_{rd}) + (D_0-D_{ld})}{2}$$

$$\Delta M_u = \frac{(M_0-M_{ru}) + (M_0-M_{lu})}{2}; \quad \Delta M_d = \frac{(M_0-M_{rd}) + (M_0-M_{ld})}{2}$$

The values for the lift, drag, and moment coefficients
given in the tables, for 0° pitch labeled "up and down, by

*These designations are used for the coefficients to avoid
awkward double subscripts.

addition" are obtained from the expressions:

$$C_L = L_o + \Delta L_u + \Delta L_d$$

$$C_D = D_o + \Delta D_u + \Delta D_d$$

$$C_M = M_o + \Delta M_u + \Delta M_d$$

The values for 0° pitch labeled "up and down, by observation" are obtained from the expressions:

$$C_L = \frac{L_{ruld} + L_{lurd}}{2}$$

$$C_D = \frac{D_{ruld} + D_{lurd}}{2}$$

$$C_M = \frac{M_{ruld} + M_{lurd}}{2}$$

Because of the general unsteadiness of the model at the high pitch angles, measurements were made only on the right aileron in the one-aileron method. The values in Tables I-IV headed "up and down, by addition" for pitch angles of 12°, 20°, and 40° were determined from the following expressions:

$$C_L = L_o + \Delta L_{ru} + \Delta L_{rd}$$

$$C_D = D_o + \Delta D_{ru} + \Delta D_{rd}$$

$$C_M = M_o + \Delta M_{ru} + \Delta M_{rd}$$

The values in the columns headed "up and down, by observation" for pitch angles of 12°, 20°, and 40° were obtained from observations made using both ailerons, displaced simultaneously in opposite directions, the right aileron up, the left one down. This method necessarily lacks the precision of the one adopted for 0° pitch in that the angles of attack at the wing tips may differ because of warping of the model or unsymmetrical air flow in the tunnel.

It will be seen from the tables that in general the observed and computed values of the lift and drag coefficients agree within a few per cent for all pitch settings.

In some cases the observed and computed pitching moment
coefficients differ decidedly when the aileron displace-
ment is greater than 24°. This appears to be due to the
combined effects of difference in angle of attack of the
wing at the tips, air spin in the tunnel, and unsteady air
flow about the model, particularly at high aileron angles.

EFFECT OF AILERON DISPLACEMENT ON WING CHARACTERISTICS

The results of this part of the investigation are
given numerically in Tables I-IV. Figures 2 to 9 illus-
trate graphically the changes in lift, drag, and center of
pressure in the case of the Clark Y wing. The results
show the effects of aileron displacement to be similar for
both the Clark Y and U.S.A. 27 wings.

In general, the changes in lift coefficient (fig. 2)
are approximately proportional to aileron displacement.
In most cases the loss in lift of the wing due to a given
upward displacement of one aileron is somewhat greater
than the gain in lift due to an equal downward displace-
ment, in agreement with the relationship existing between
the corresponding rolling moments, noted in references 3
and 4. The total lift of the wing is therefore decreased
slightly when the ailerons are displaced equally and si-
multaneously, one up, the other down. (Fig. 2.) The
marked change in the slope of the curve of lift coeffi-
cient against aileron angle (fig. 2) which occurs above
the 24° point, is in substantial agreement with the change
in slope of the rolling moment curve for the same condi-
tions.

The upward displacement of one aileron causes a de-
crease in total drag through a large range of aileron
travel, as illustrated in Figure 3. In the case of the
20 by 2 inch aileron on the Clark Y wing, 0° pitch (fig.
3), the total drag as compared with the drag when the ai-
leron is neutral, is reduced throughout the range of ai-
leron travel between 0° and 23°. The maximum reduction,
13 per cent, occurs when the displacement is 11°. When
the pitch angle is increased to 12° the region of reduced
drag extends beyond the 44° aileron displacement. The
maximum reduction in drag coefficient for a pitch angle
of 12° is 15 per cent and occurs when the aileron is dis-
placed 22°. The change in direction of the drag incre-
ment due to the upward displacement of one aileron is in

agreement with the reversal in direction of the yawing moment. Simultaneous displacement of both ailerons, equally but in opposite directions, results in increasing the drag of the model for all conditions investigated.

The center of pressure positions were computed using the observed values of lift, drag, and pitching moment. Upward displacement of one aileron causes the center of pressure of the model to move forward. The amount of movement depends on the amount of upward aileron displacement and on the pitch angle of the model as illustrated in Figures 4-9. Reference to Figure 4 and to the tables will show that the amount of center of pressure movement is also governed by the aileron chord, being definitely greater for displacements of more than 24° in the case of the larger ailerons. When both large chord ailerons are displaced equally but in opposite directions, the pitch angle being 0°, the center of pressure moves less than when one large chord aileron is displaced upward. The travel of the center of pressure on the model due to aileron displacement is relatively greater than the travel due to changing the angle of pitch within the range of these tests. Referring to Table I, for example, displacing both ailerons 24° with 0° pitch angle reduces the value of the center of pressure coefficient from 0.34 to 0.28, while increasing the pitch from 0° to 20° with ailerons neutral reduces the value of C_p from 0.34 to 0.32.

CONCLUSION

A comparison of the results obtained by the one-aileron and the two-aileron methods of estimating the performance of the conventional arrangement indicates that neglecting mutual interference between the ailerons is not an important factor affecting the precision of the results. The most disturbing factors appear to arise from (1) difference in the angle of attack of the wing at the tips and at midspan due to warping or to wind loading during a run and (2) spin in the tunnel air stream.

The effects of the upward displacement of one aileron determined as a result of this investigation are:

1. A reduction in total lift, the amount of the reduction depending on the chord of the aileron and the displacement.

2. A reduction in total drag at least until the aileron displacement becomes very large.

3. A forward travel of the center of pressure of the model. In general, this travel is comparable with or a little greater than the travel due to the displacement of both ailerons in the conventional manner.

Bureau of Standards,
    Washington, D. C., October 13, 1932.

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TABLE I. CHARACTERISTICS OF CLARK Y AIRFOIL AND FUSELAGE, WITH 20 BY 2 INCH AILERONS

θ	δ_A	Lift coefficient				Drag coefficient				Moment coefficient				c_p		
		Up	Down	Up and down (by addition)	(by observation)	Up	Down	Up and down (by addition)	(by observation)	Up	Down	Up and down (by addition)	(by observation)	Up	Down	Up and dn. (by observation)
0°	0°	0.71	0.71	0.71	0.71	0.053	0.053	0.053	0.053	0.67	0.67	0.67	0.67	0.34	0.34	0.34
	4°	.67	.76	.72	.71	.050	.059	.056	.054	.62	.72	.67	.66	.32	.35	.33
	8°	.61	.82	.72	.70	.047	.066	.059	.059	.56	.77	.66	.65	.31	.34	.33
	16°	.53	.90	.72	.69	.048	.078	.073	.070	.45	.85	.63	.62	.26	.34	.29
	24°	.49	.92	.70	.67	.054	.089	.090	.090	.43	.86	.62	.59	.27	.33	.28
	32°	.42	.97	.68	.66	.061	.105	.113	.111	.35	.89	.57	.58	.24	.33	.24
	40°	.38	1.00	.65	.64	.070	.118	.135	.133	.28	.91	.52	.52	.19	.31	.21
	44°	.35	1.00	.64	.62	.076	.123	.146	.145	.26	.91	.50	.48	.15	.31	.17
12°	0°	1.11	1.11	1.11	1.11	0.20	0.20	0.20	0.20	1.06	1.06	1.06	1.03	0.34	0.34	0.34
	4°	1.11	1.11	1.11	1.09	.20	.21	.21	.20	1.05	1.07	1.06	1.03	.33	.35	.33
	8°	1.08	1.11	1.08	1.11	.19	.22	.21	.21	1.02	1.06	1.02	1.03	.34	.34	.32
	16°	1.03	1.12	1.04	1.07	.18	.24	.21	.21	.95	1.07	.97	.99	.31	.34	.30
	24°	1.01	1.13	1.03	1.05	.17	.25	.22	.21	.92	1.10	.96	.96	.30	.35	.30
	32°	1.02	1.14	1.05	1.08	.18	.27	.25	.24	.92	1.10	.96	.98	.29	.34	.29
	40°	1.01	1.16	1.06	1.07	.18	.29	.28	.26	.91	1.12	.97	.97	.29	.34	.28
	44°	0.98	1.16	1.03	1.07	.18	.28	.26	.27	.87	1.12	.93	.95	.26	.34	.25
20°	0°	0.92	0.92	0.92	0.92	0.48	0.48	0.48	0.48	0.95	0.95	0.95	0.95	0.32	0.32	0.32
	4°	.92	.92	.92	.93	.47	.49	.48	.49	.95	.95	.95	.95	.32	.33	.32
	8°	.90	.92	.90	.89	.46	.50	.48	.48	.95	.95	.95	.91	.34	.33	.28
	16°	.87	.93	.87	.89	.45	.51	.48	.49	.88	.95	.87	.91	.30	.35	.28
	24°	.84	.95	.87	.86	.44	.55	.52	.50	.83	.97	.85	.86	.29	.37	.21
	32°	.84	.97	.89	.86	.45	.58	.55	.52	.83	1.00	.88	.86	.28	.36	.19
	40°	.85	.97	.90	.86	.46	.58	.58	.54	.83	1.00	.88	.85	.27	.35	.17
	44°	.85	.97	.90	.86	.47	.58	.57	.55	.83	1.00	.88	.85	.27	.35	.17
40°	0°	0.87	0.87	0.87	0.87	0.92	0.92	0.92	0.92	1.19	1.19	1.19	1.19	0.34	0.34	0.34
	4°	.86	.86	.85	.86	.91	.91	.91	.91	1.15	1.19	1.15	1.16	.32	.35	.33
	8°	.84	.86	.83	.85	.90	.92	.90	.90	1.12	1.19	1.13	1.14	.32	.35	.33
	16°	.82	.88	.83	.84	.87	.95	.90	.91	1.09	1.21	1.10	1.16	.31	.34	.32
	24°	.80	.87	.80	.84	.85	.96	.89	.91	1.06	1.19	1.08	1.16	.31	.33	.33
	32°	.78	.88	.79	.82	.84	.96	.88	.91	1.01	1.20	1.02	1.09	.29	.33	.26
	40°	.78	.90	.81	.82	.84	1.00	.92	.94	1.03	1.21	1.05	1.11	.31	.33	.26
	44°	.80	.90	.83	.85	.85	1.01	.94	.96	1.07	1.24	1.12	1.16	.33	.33	.29

TABLE II. CHARACTERISTICS OF CLARK Y AIRFOIL AND FUSELAGE, WITH 20 BY 3 INCH AILERONS

θ	δ_A	Lift coefficient				Drag coefficient				Moment coefficient				c_p		
		Up	Down	Up and down (by addition)	(by observation)	Up	Down	Up and down (by addition)	(by observation)	Up	Down	Up and down (by addition)	(by observation)	Up	Down	Up and dn (by observation)
0°	0°	0.71	0.71	0.71	0.71	0.053	0.053	0.053	0.053	0.67	0.67	0.67	0.67	0.34	0.34	0.34
	4°	.63	.76	.69	.69	.048	.059	.054	.053	.59	.73	.65	.65	.34	.36	.34
	8°	.58	.81	.68	.67	.045	.066	.058	.058	.54	.78	.65	.64	.33	.35	.35
	16°	.48	.89	.66	.64	.048	.084	.079	.077	.43	.85	.62	.58	.27	.34	.31
	24°	.42	.95	.65	.62	.059	.099	.105	.104	.35	.90	.58	.53	.21	.37	.25
	32°	.35	.96	.59	.59	.073	.118	.137	.137	.27	.90	.50	.47	.16	.33	.19
	40°	.29	1.00	.58	.55	.088	.137	.172	.172	.18	.92	.43	.39	.01	.33	.11
	44°	.26	1.02	.57	.55	.095	.150	.192	.189	.15	.94	.42	.37	-.02	.34	.06
12°	0°	1.11	1.11	1.11	1.11	0.20	0.20	0.20	0.20	1.06	1.06	1.06	1.06	0.34	0.34	0.34
	4°	1.10	1.13	1.13	1.12	.19	.21	.20	.20	1.05	1.09	1.07	1.06	.34	.34	.33
	8°	1.07	1.13	1.08	1.10	.18	.22	.20	.20	1.01	1.08	1.03	1.03	.33	.35	.33
	16°	1.01	1.14	1.04	1.03	.16	.25	.21	.20	.90	1.08	.93	.93	.28	.33	.28
	24°	.93	1.15	0.97	0.99	.15	.26	.21	.20	.78	1.10	.83	.88	.23	.33	.28
	32°	.88	1.16	.93	.96	.16	.28	.24	.23	.74	1.11	.79	.82	.23	.33	.23
	40°	.88	1.18	.95	.94	.17	.32	.29	.27	.72	1.12	.78	.76	.20	.33	.17
	44°	.81	1.19	.89	.91	.17	.34	.30	.28	.64	1.14	.72	.73	.18	.33	.17
20°	0°	0.92	0.92	0.93	0.93	0.48	0.48	0.48	0.48	0.95	0.95	0.95	0.95	0.32	0.32	0.32
	4°	.90	.92	.90	.92	.47	.50	.49	.49	.91	.99	.95	.95	.30	.35	.34
	8°	.88	.92	.88	.92	.46	.50	.48	.50	.87	.97	.90	.93	.29	.34	.30
	16°	.85	.92	.85	.90	.44	.54	.50	.50	.85	1.00	.90	.90	.29	.35	.28
	24°	.83	.96	.87	.87	.43	.56	.51	.50	.81	1.00	.86	.85	.24	.31	.26
	32°	.84	.96	.88	.86	.42	.58	.52	.53	.81	1.00	.86	.80	.26	.31	.21
	40°	.83	.96	.87	.86	.43	.60	.55	.55	.80	1.01	.83	.80	.28	.29	.20
	44°	.82	.96	.86	.86	.44	.61	.57	.56	.77	.99	.81	.80	.24	.29	.20
40°	0°	0.87	0.87	0.87	0.87	0.92	0.92	0.92	0.92	1.19	1.19	1.19	1.19	0.34	0.34	0.34
	4°	.89	.91	.93	.88	.84	.93	.97	.91	1.23	1.27	1.31	1.19	.27	.38	.34
	8°	.90	.92	.95	.88	.96	.95	.99	.93	1.24	1.29	1.34	1.19	.34	.38	.33
	16°	.88	.94	.95	.87	.91	.96	.95	.93	1.20	1.30	1.31	1.15	.35	.38	.31
	24°	.85	.93	.91	.86	.88	.99	.95	.94	1.14	1.29	1.24	1.13	.34	.36	.29
	32°	.80	.92	.85	.85	.86	1.01	.95	.93	1.06	1.26	1.16	1.09	.31	.35	.27
	40°	.79	.92	.84	.80	.86	1.02	.96	.91	1.05	1.26	1.13	1.07	.31	.33	.24
	44°	.82	.91	.86	.82	.86	1.03	.97	.93	1.10	1.25	1.16	1.05	.33	.32	.26

TABLE III.　CHARACTERISTICS OF U.S.A. 27 AIRFOIL AND FUSELAGE, WITH 20 BY 2 INCH AILERONS

θ	δ_A	Lift coefficient				Drag coefficient				Moment coefficient				c_p		
		Up	Down	Up and down (by addi-tion)	(by obser-vation)	Up	Down	Up and down (by addi-tion)	(by obser-vation)	Up	Down	Up and down (by addi-tion)	(by obser-vation)	Up	Down	Up and dn (by obser-vation)
0°	0°	0.68	0.68	0.68	0.68	0.043	0.043	0.043	0.043	0.62	0.62	0.62	0.62	0.31	0.31	0.31
	4	.59	.72	.63	.65	.035	.046	.038	.041	.53	.66	.56	.58	.28	.31	.29
	8	.52	.76	.60	.64	.034	.050	.041	.046	.48	.72	.58	.57	.30	.35	.29
	16	.50	.82	.64	.62	.037	.061	.058	.056	.44	.78	.56	.53	.28	.35	.28
	24	.48	.84	.64	.61	.041	.069	.067	.072	.42	.80	.60	.53	.27	.35	.27
	32	.33	.90	.65	.58	.050	.086	.093	.091	.34	.84	.56	.44	.29	.33	.18
	40	.37	.93	.62	.57	.058	.096	.101	.107	.27	.86	.51	.41	.21	.32	.12
	44	.35	.93	.60	.58	.068	.102	.124	.139	.24	.86	.48	.39	.18	.32	.09
12°	0°	1.20	1.20	1.20	1.20	0.17	0.17	0.17	0.17	1.15	1.15	1.15	1.15	0.35	0.35	0.35
	4°	1.19	1.21	1.20	1.19	.16	.18	.17	.17	1.15	1.18	1.16	1.14	.36	.35	.35
	8°	1.18	1.23	1.21	1.20	.15	.19	.17	.17	1.15	1.19	1.19	1.15	.37	.35	.35
	16°	1.15	1.26	1.21	1.18	.14	.20	.17	.17	1.09	1.21	1.15	1.11	.34	.35	.33
	24°	1.13	1.26	1.21	1.17	.14	.22	.19	.19	1.06	1.24	1.15	1.07	.34	.35	.30
	32°	1.11	1.26	1.19	1.17	.15	.23	.20	.20	1.03	1.25	1.13	1.09	.33	.35	.31
	40°	1.09	1.26	1.17	1.16	.15	.24	.21	.21	1.01	1.24	1.10	1.05	.32	.35	.30
	44°	1.08	1.26	1.16	1.17	.15	.25	.23	.23	0.97	1.24	1.06	1.06	.30	.35	.27
20°	0°	1.02	1.02	1.02	1.02	0.38	0.38	0.38	0.38	1.06	1.06	1.06	1.06	0.37	0.37	0.37
	4°	0.99	1.03	1.00	1.03	.35	.39	.36	.38	1.05	1.06	1.05	1.09	.39	.37	.39
	8°	.99	1.04	1.01	1.04	.34	.39	.35	.37	1.04	1.07	1.05	1.10	.39	.37	.39
	16°	.98	1.08	1.04	1.04	.33	.41	.36	.39	1.02	1.12	1.08	1.07	.39	.37	.37
	24°	.95	1.08	1.01	1.03	.32	.45	.39	.41	0.97	1.10	1.01	1.04	.37	.34	.34
	32°	.97	1.08	1.03	1.03	.33	.47	.42	.46	1.00	1.11	1.05	1.05	.38	.34	.33
	40°	.95	1.12	1.05	1.02	.35	.47	.44	.47	0.99	1.14	1.07	1.02	.37	.34	.31
	44°	.96	1.13	1.07	1.02	.34	.50	.46	.47	.97	1.13	1.03	1.02	.38	31	.31
40°	0°	0.90	0.90	0.90	0.90	0.88	0.88	0.88	0.88	1.23	1.23	1.23	1.22	0.38	0.38	0.38
	4°	.90	.91	.91	.92	.89	.89	.90	.89	1.20	1.25	1.23	1.25	.36	.39	.38
	8°	.90	.92	.92	.92	.88	.90	.90	.90	1.20	1.26	1.24	1.24	.36	.38	.37
	16°	.89	.93	.92	.92	.87	.90	.89	.90	1.19	1.27	1.24	1.24	.36	.39	.36
	24°	.85	.95	.90	.89	.85	.94	.91	.94	1.14	1.31	1.23	1.19	.35	.39	.34
	32°	.82	.94	.86	.86	.83	.94	.89	.94	1.09	1.39	1.16	1.14	.34	.37	.33
	40°	.85	.96	.91	.89	.86	.97	.95	.97	1.12	1.31	1.21	1.17	.33	.37	.32
	44°	.87	.96	.93	.88	.86	.97	.95	.97	1.15	1.31	1.24	1.19	.34	.37	.33

TABLE IV.　CHARACTERISTICS OF U.S.A. 27 AIRFOIL AND FUSELAGE, WITH 20 BY 3 INCH AILERONS

θ	δ_A	Lift coefficient				Drag coefficient				Moment coefficient				c_p		
		Up	Down	Up and down (by addi-tion)	(by obser-vation)	Up	Down	Up and down (by addi-tion)	(by obser-vation)	Up	Down	Up and down (by addi-tion)	(by obser-vation)	Up	Down	Up and dn (by obser-vation)
0°	0°	0.68	0.68	0.68	0.68	0.043	0.043	0.043	0.043	0.62	0.62	0.62	0.62	0.31	0.31	0.31
	4°	.61	.73	.66	.67	.039	.048	.044	.045	.54	.66	.58	.59	.29	.33	.28
	8°	.54	.77	.65	.65	.034	.053	.044	.050	.47	.71	.56	.58	.26	.33	.26
	16°	.44	.82	.57	.58	.041	.069	.065	.066	.37	.74	.49	.49	.24	.30	.25
	24°	.40	.87	.58	.57	.049	.088	.094	.096	.33	.78	.49	.45	.23	.33	.20
	32°	.35	.90	.57	.58	.065	.106	.128	.128	.26	.81	.45	.44	.14	.30	.15
	40°	.29	.93	.54	.56	.076	.121	.155	.158	.19	.81	.38	.40	.05	.27	.09
	44°	.26	.95	.52	.54	.086	.137	.170	.174	.15	.83	.35	.35	0	.28	.05
12°	0°	1.20	1.20	1.20	1.20	0.17	0.17	0.17	0.17	1.15	1.15	1.15	1.15	0.35	0.35	0.35
	4°	1.19	1.24	1.23	1.18	.16	.18	.17	.17	1.14	1.18	1.18	1.15	.35	.35	.36
	8°	1.14	1.34	1.18	1.19	.14	.20	.17	.17	1.07	1.20	1.13	1.11	.34	.38	.33
	16°	1.07	1.23	1.10	1.13	.13	.22	.18	.18	1.00	1.19	1.04	1.03	.33	.35	.31
	24°	1.00	1.25	1.05	1.04	.12	.23	.19	.18	0.90	1.20	0.95	0.92	.30	.34	.27
	32°	0.99	1.24	1.03	1.05	.13	.25	.21	.22	.87	1.19	.91	.91	.28	.35	.24
	40°	.96	1.26	1.02	1.01	.14	.27	.24	.24	.85	1.19	.89	.88	.27	.32	.23
	44°	.94	1.24	0.98	0.98	.15	.27	.25	.25	.81	1.19	.85	.81	.25	.33	.20
20°	0°	1.02	1.02	1.02	1.02	0.38	0.38	0.38	0.38	1.06	1.06	1.06	1.06	0.37	0.37	0.37
	4°	1.00	1.04	1.02	1.03	.38	.39	.39	.38	1.03	1.08	1.06	1.06	.37	.38	.38
	8°	1.00	1.06	1.04	1.03	.36	.42	.40	.40	1.02	1.11	1.07	1.06	.36	.38	.36
	16°	0.96	1.08	1.02	1.04	.35	.44	.41	.41	0.97	1.14	1.05	1.06	.35	.37	.35
	24°	.91	1.08	0.97	0.97	.31	.47	.40	.43	.90	1.14	0.98	0.97	.34	.36	.32
	32°	.88	1.07	0.93	.94	.31	.48	.42	.45	.87	1.14	.95	.91	.33	.37	.28
	40°	.93	1.09	1.00	.96	.32	.52	.46	.48	.90	1.14	.98	.92	.32	.34	.27
	44°	.91	1.07	0.96	.98	.33	.53	.47	.48	.88	1.09	.91	.93	.32	.30	.26
40°	0°	0.90	0.90	0.90	0.90	0.88	0.88	0.88	0.88	1.22	1.22	1.22	1.22	0.38	0.38	0.38
	4°	.90	.90	.90	.91	.87	.92	.92	.89	1.22	1.21	1.21	1.24	.38	.35	.38
	8°	.88	.92	.90	.90	.84	.92	.92	.89	1.20	1.25	1.23	1.22	.39	.36	.37
	16°	.86	.95	.91	.88	.87	.96	.95	.90	1.15	1.30	1.23	1.20	.35	.37	.36
	24°	.83	.93	.86	.87	.83	.97	.92	.90	1.10	1.29	1.17	1.16	.34	.36	.34
	32°	.81	.92	.83	.82	.81	.98	.91	.90	1.06	1.30	1.14	1.08	.33	.37	.30
	40°	.77	.91	.78	.77	.81	.99	.92	.88	1.02	1.25	1.05	1.02	.32	.34	.29
	44°	.82	.91	.83	.84	.83	1.00	.95	.84	1.08	1.24	1.10	1.00	.34	.32	.29

Fig. 1a

Fig. 1b

Figs. 1a and 1b Drawing of model and arrangement of balances.

Clark Y -20 x 2 ailerons.

×——————— One aileron up.
○-------------- "   "   down.
△·-·—·—·— "   "   up, other down $(+\delta_A = -\delta_A)$

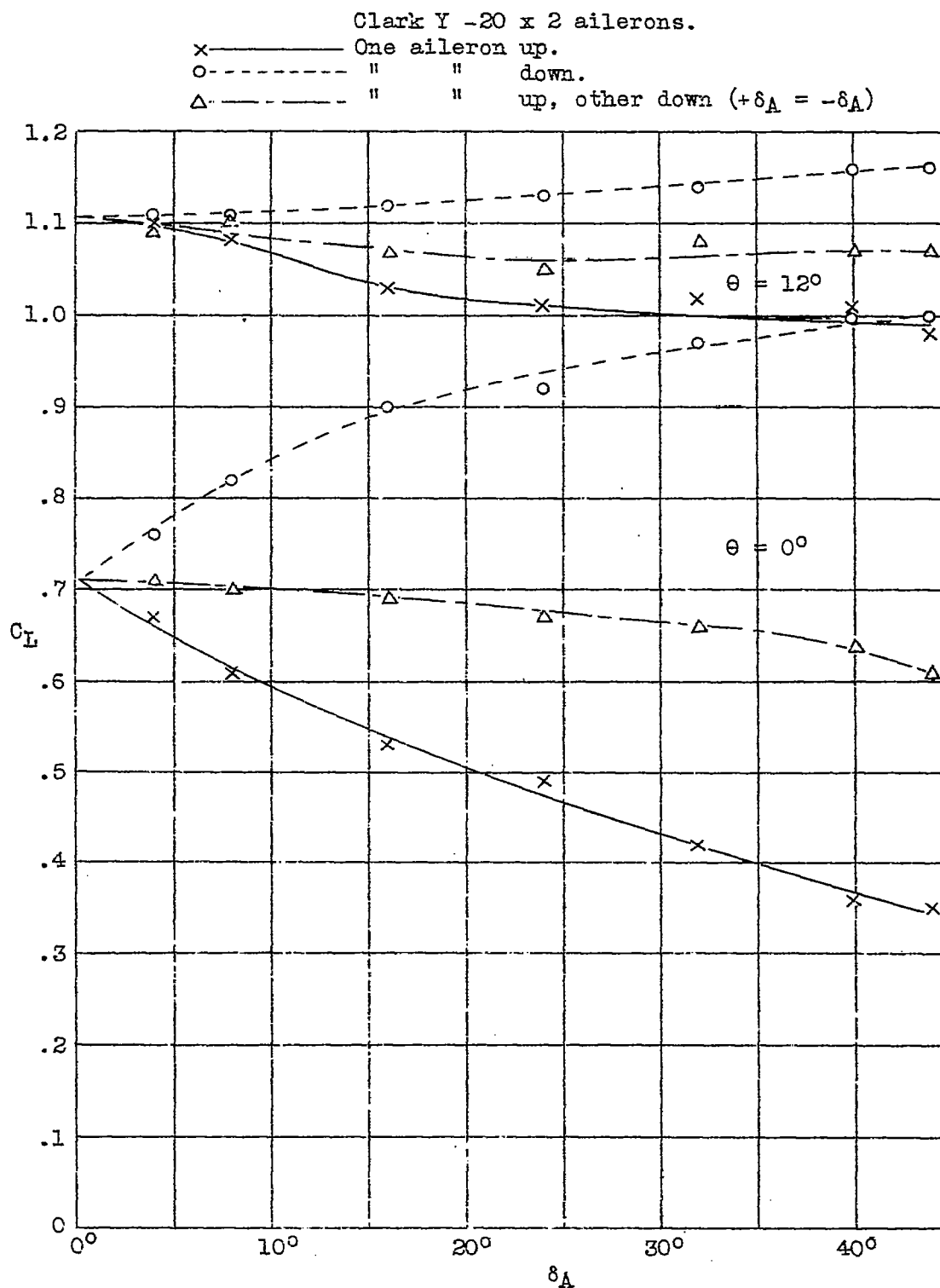Figure 2.- Variation of lift coefficient with aileron displacement.

Figure 3.- Variation of drag coefficient with aileron displacement.
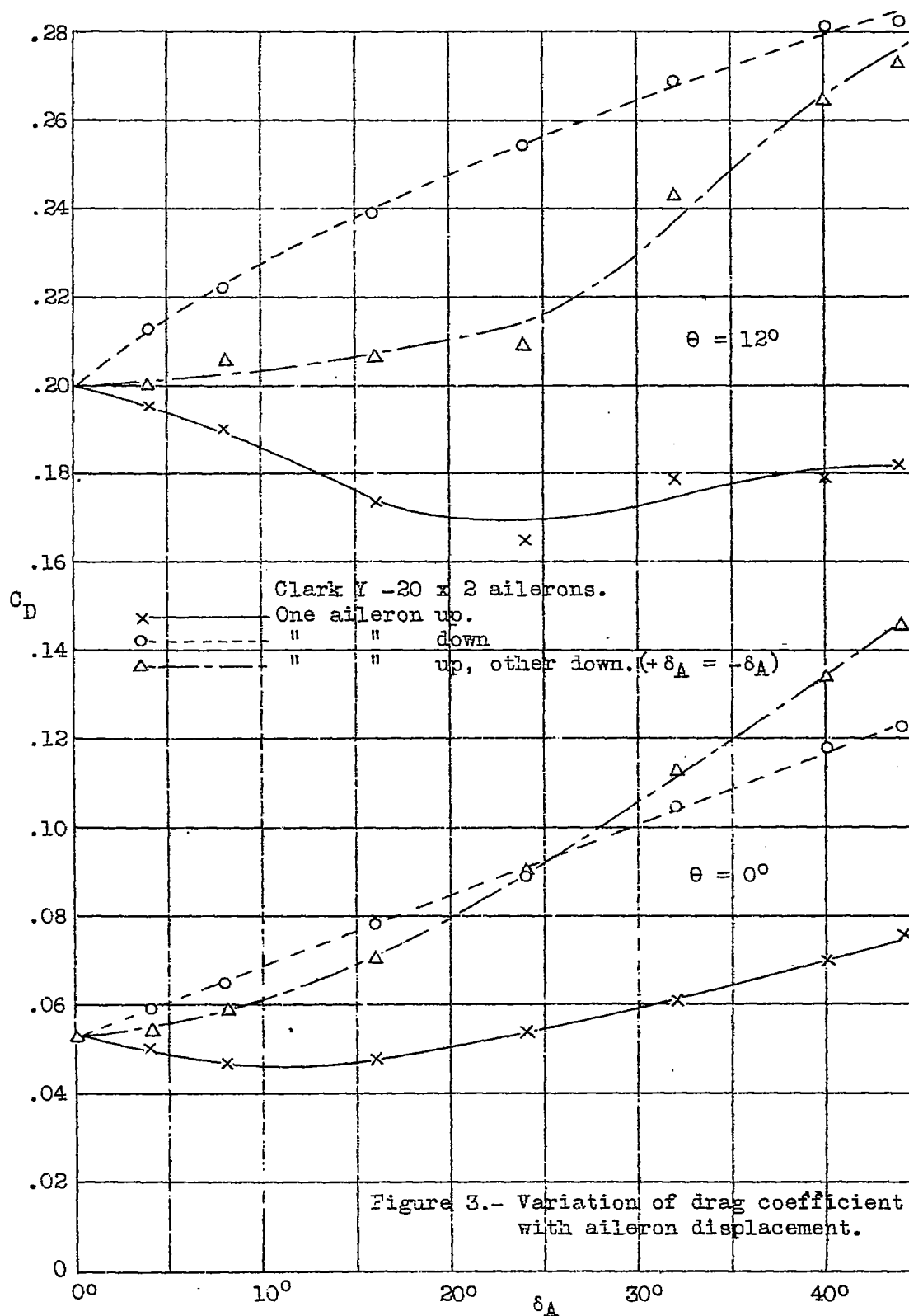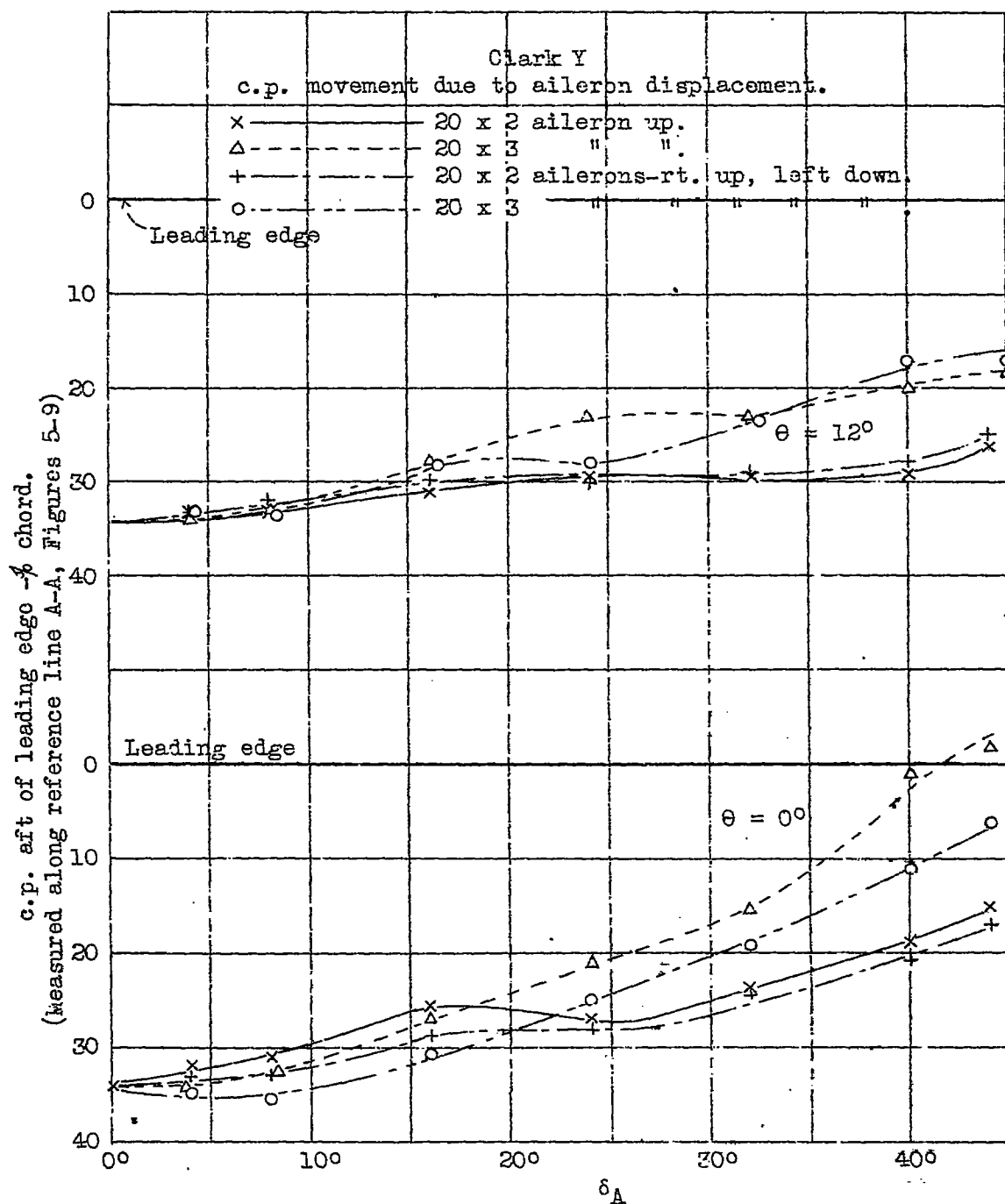
Figure 4.- Typical center of pressure curves.

Wind

Moment center, O

a, $\delta_A = 0^0$
b, " $= 8^0$
c, " $=16^0$
d, " $=32^0$
e, " $=40^0$
f, " $=44^0$

Scale of drawing
10 inches
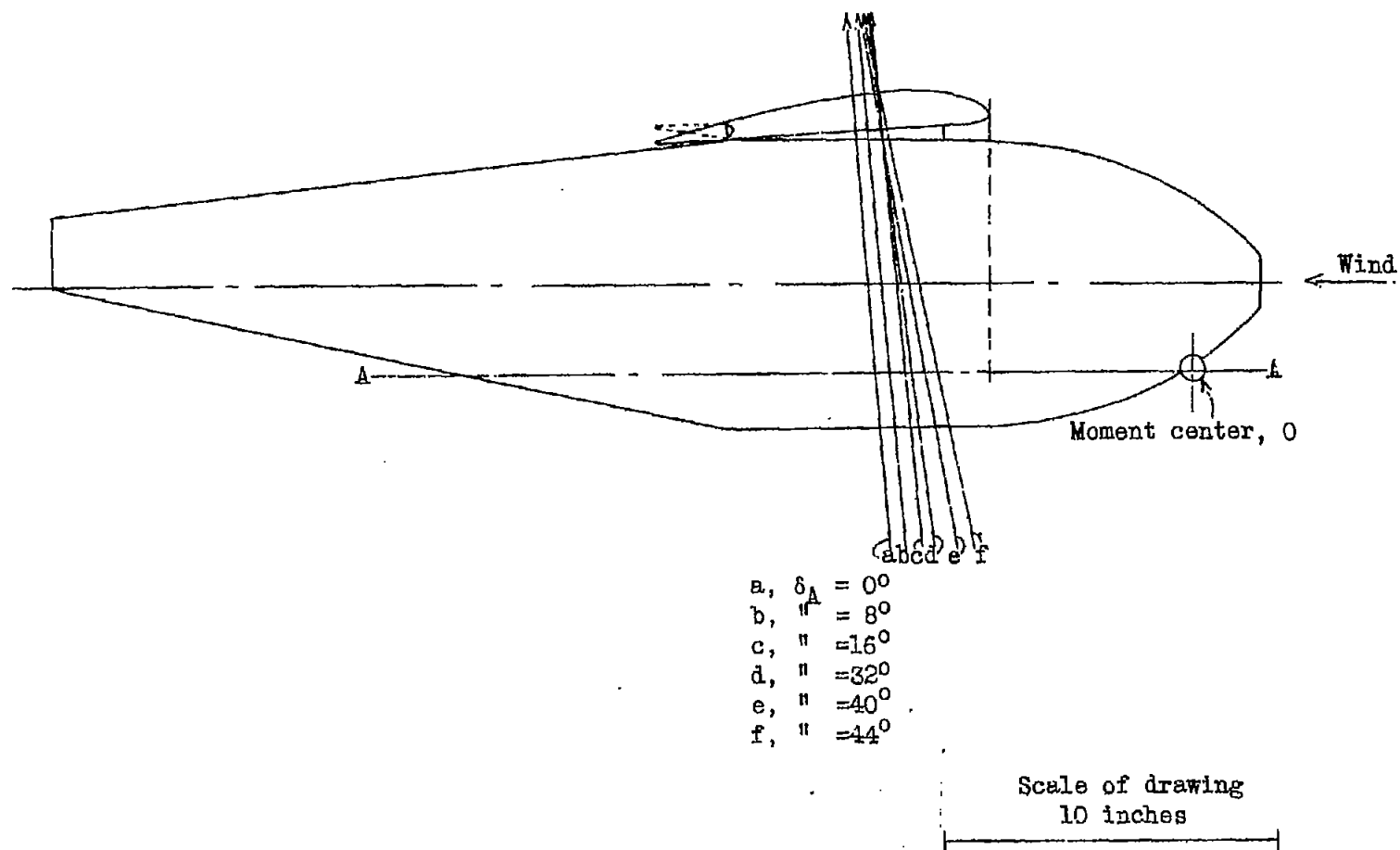
Figure 5.-Vector diagram, 20 by 2 inch aileron up. $\theta = 0^0$. Clark Y airfoil.

Fig. 5

a, $\delta_A = 0°$
b, " $=16°$
c, " $=32°$
d, " $=44°$

Scale of drawing
10 inches

Figure 6.-Vector diagram, 20 by 2 inch aileron up. $\theta = 12°$. Clark Y airfoil.

Fig.6

20°

Wind

A

Moment center

a
b c
d

a, $\delta_A = 0°$
b, " $= 16°$
c, " $= 32°$
d, " $= 44°$

Scale of drawing
10 inches
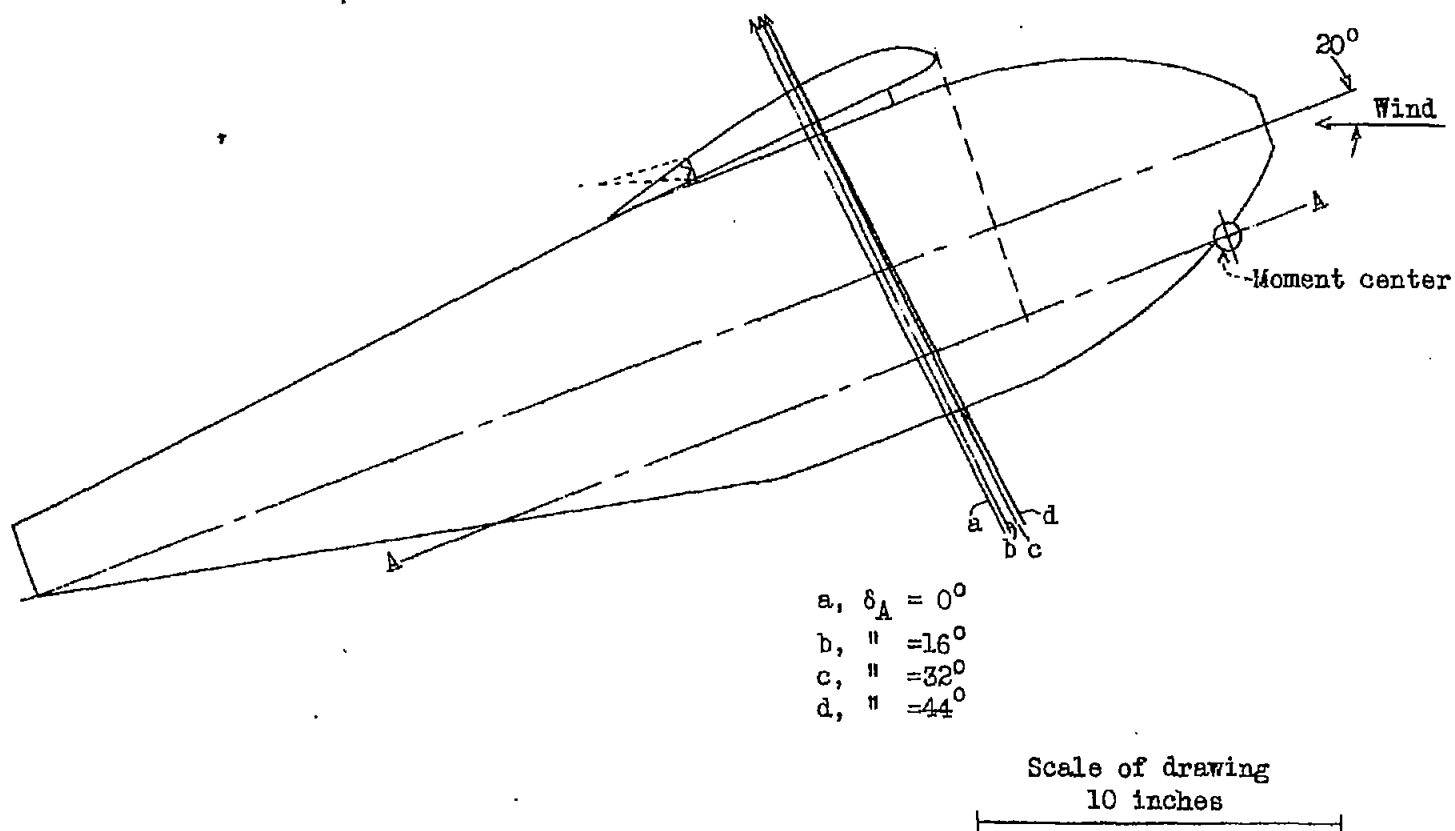
Figure 7.--Vector diagram, 20 by 2 inch aileron up. $\theta = 20°$. Clark Y airfoil.

Fig.7

40° Wind

A

Moment center

c
a
b

a, $\delta_A = 0°$
b, " $=32°$
c, " $=44°$

A

Scale of drawing
10 inches
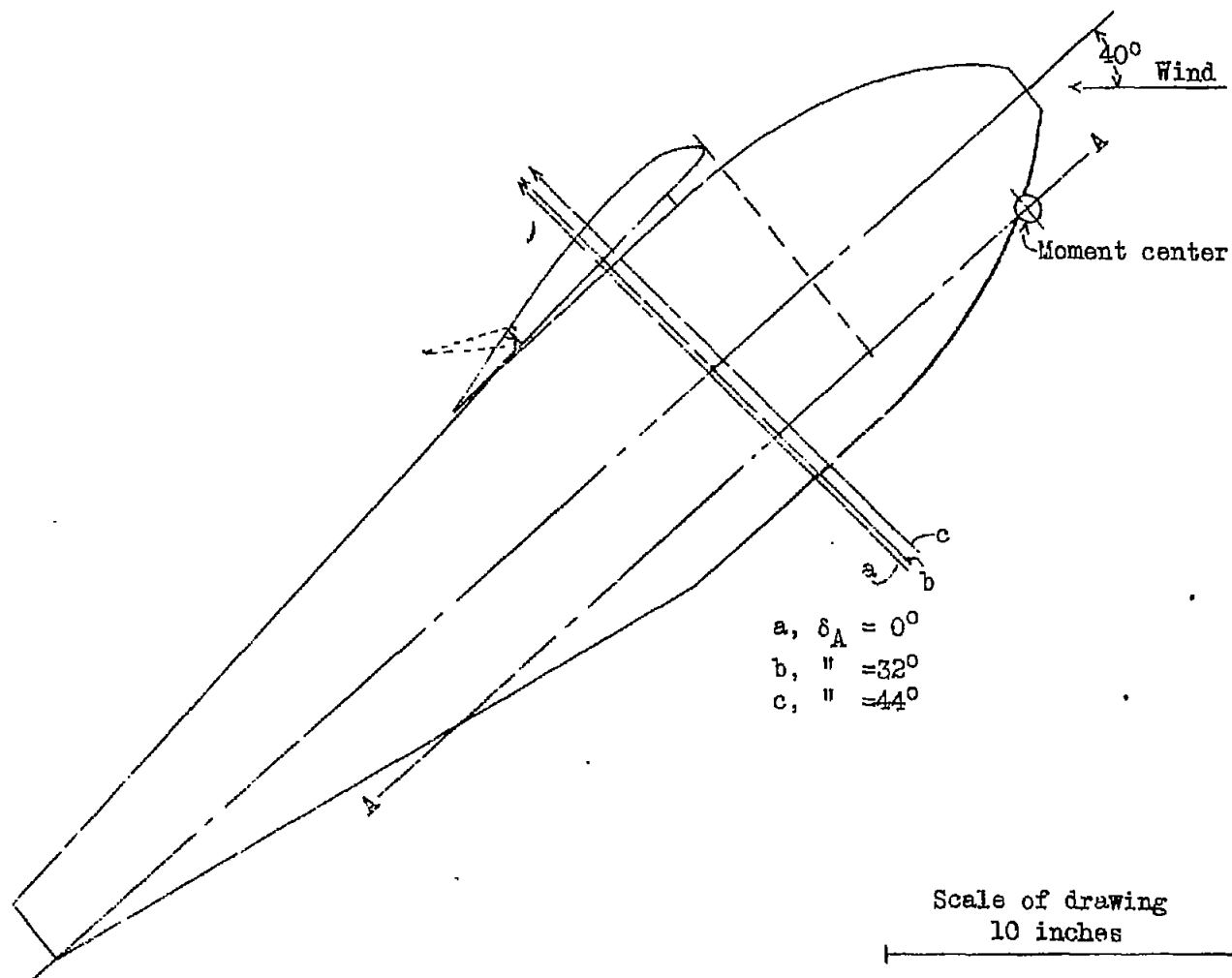
Figure 8.-Vector diagram, 30 by 2 inch aileron up. $\theta = 40°$. Clark Y airfoil.

Fig. 8

Wind

A ———— A

Moment center, O

a, $\delta_A = 0^0$
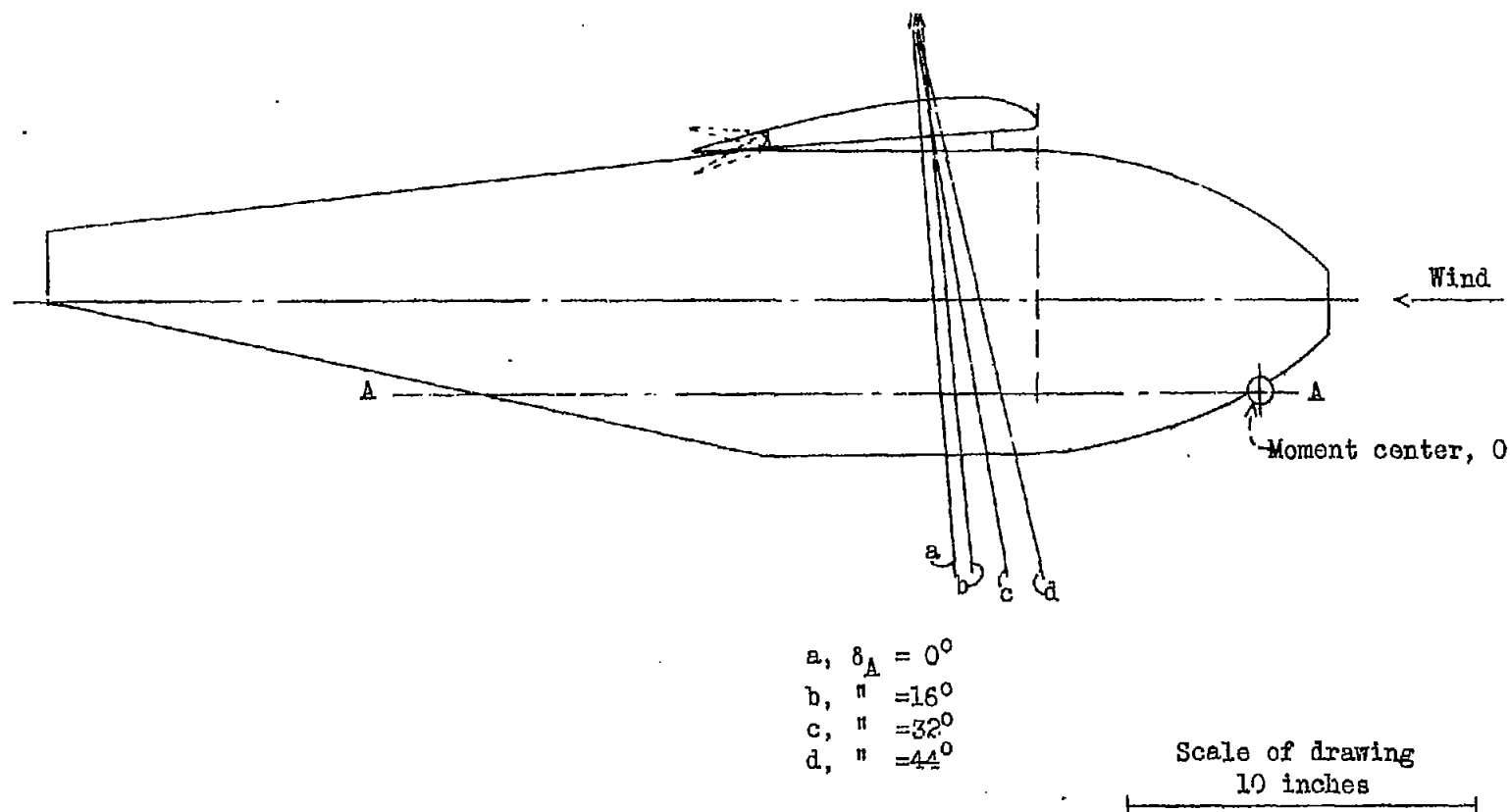b, " $=16^0$
c, " $=32^0$
d, " $=44^0$

Scale of drawing
10 inches

Figure 9.-Vector diagram, 20 by 2 inch aileron, right up, left down. $\theta = 0^0$. Clark Y airfoil.

Fig.9